AUTOMOTIVE EDUCATION GUIDE

2026

INTERNATIONAL WINDOW FILM ASSOCIATION®

Foreword

The following material presented in this educational study guide is provided for the education of window film industry participants. Our hope is that IWFA members and non-members will use the information provided to promote window film professionally and competently. Additionally, accreditation tests are available through the IWFA education system. Passing grades on each test will give IWFA members additional accreditation references on the IWFA dealer locator.

The information presented has been reviewed for technical accuracy by the IWFA Technical Committee. Therefore, we believe this guide presents a wide range of materials in a balanced and unbiased format. We not only welcome but encourage readers and users to continually offer suggestions for future edits.

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We sincerely hope the use of this Guide in your business dealings will enhance your professional development and success.

IWFA Board of Directors

Introduction

The biggest problem in controlling comfort, glare, and interior deterioration in vehicles is dealing with radiant energy from the sun. While the metal body of the vehicle absorbs this energy, it literally pours through windows and is absorbed by all it touches. The larger the glass area, the larger the impact. This Guide will focus on describing the sun's energy journey through the atmosphere, interaction with clear glass, variations in glass types and coatings, window film constructions, and finally the measurement and impact of solar radiation on vehicles.

The Sun – A Source of Radiant Electromagnetic Energy

The sun is a tremendous source of energy. It is constantly sending its energy through space towards the earth in the form of electromagnetic radiation or energy waves. This transfer of heat from the sun to earth is called radiation. Throughout this Guide it will be important to remember that heat energy always flows from high temperature to lower temperatures. Freezers and coolers don't "keep the cold in," they prevent heat from entering and warming the interior contents. Earth's atmosphere protects it from the sun's energy reaching the surface. Changes in that atmosphere can change the rate at which that heat transfer occurs.

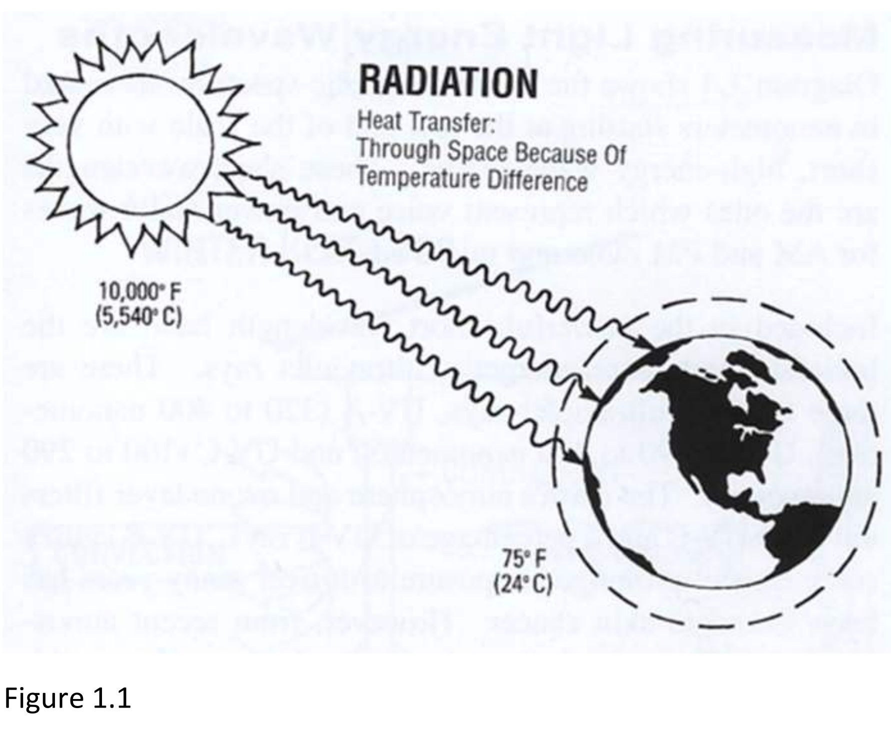


Figure 1.1

Electromagnetic energy is expressed in units called wavelengths. A wavelength is the length of a full cycle in a repeating curve. As electromagnetic waves are impossible to see with normal vision, it is helpful to use an example of something visual like the waves formed in a bowl of water in contact with a vibrating needle. The wavelength is the distance from the beginning of a positive phase through positive and negative phases to the beginning of the next positive phase.

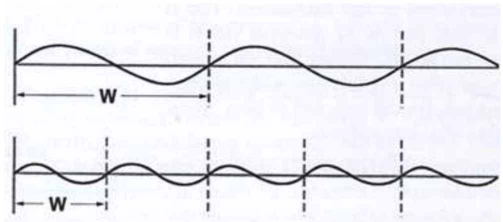


Figure 1.2

Individual waves are not visible within the electromagnetic spectrum, although human senses and biology interact with these wavelengths in many ways. These waves are measured in nanometers. A nanometer (nm) equals one billionth of a meter or 0.0000000394 inches! Another common measure of electromagnetic energy is frequency, a measure of the number of wavelengths per second. Using the bowl and needle example, the frequency could be visualized by the number of waves hitting the side of the bowl per second. Figure 1.3 below shows the electromagnetic spectrum from shorter, higher frequency wavelengths up to the longer, low frequency wavelengths. Note that not all electromagnetic wavelengths are part of the solar spectrum.

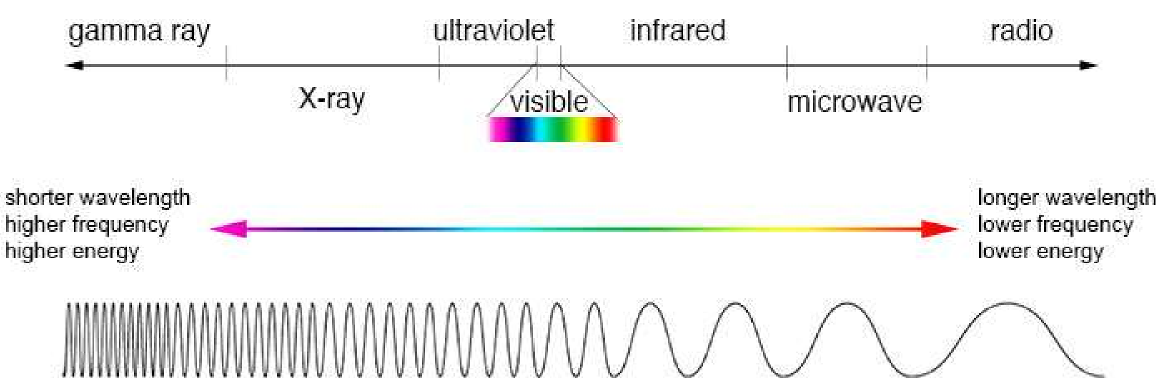


Figure 1.3

Measuring Light Energy Wavelengths

Figure 1.4 shows the electromagnetic spectrum, with nanometer measurements, starting at the low level of the scale with very short, high-energy wavelengths. Energy from the sun is only found in a portion of the electromagnetic (EM) spectrum and is referred to as the solar spectrum.

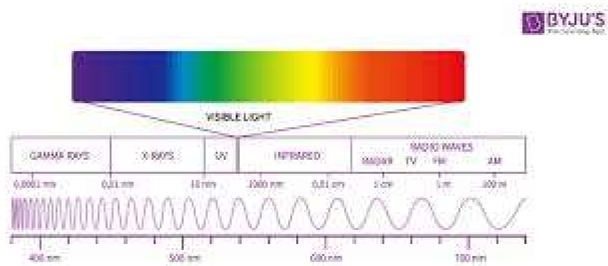


Figure 1.4

Ultraviolet

Included in the powerful, short wavelength band are the invisible and more energetic (higher frequency) ultraviolet rays. There are three types of ultraviolet rays: UV-C (100 – 290 nanometers), UV-B (290 – 320 nanometers), and UV-A (320 – 400 nanometers). The earth's atmosphere and ozone layer filter out most UV-C and a percentage of the UV-B.

Visible

What is considered the visible band of the solar spectrum runs from roughly 380 nanometers to 780 nanometers. "Visible" is a subjective term as there are no globally agreed limits to the visible spectrum. CIE (International Commission on Illumination) defines the visible radiation as "any optical radiation capable of causing a visual sensation." Age plays a significant role in a person's ability to see. UV absorption increases in the human lens over time thus blocking more and more of the UV region. This is nature's way of protecting the eye, as excessive UV is a strong contributor to macular degeneration. Most spectral charts show the UV region overlapping with the visible region between 380-400 nm. Industry standard measurements will be reviewed later in this Guide. A similar situation occurs at the top range of the visible region. Most experts believe the range where humans start to lose the ability to perceive light is somewhere between 760 – 830 nm. Above this range are other invisible rays that we cannot see as light but can only feel as heat. These are called infrared rays.

Infrared

Infrared is electromagnetic energy with wavelengths greater than that of red visible light. Infrared is in the solar spectrum from 780 nanometers to greater than 1 millimeter. There are different ranges in the Infrared regions. Near- IR is from 780 – 2500 nm. Far-IR radiation is re-radiated from objects that have been heated by the sun or other heat sources. Far-IR is measured from 2500 nm to 40,000 nm. Beyond that point the amount of radiation from the sun is extremely low.

Solar Heat: Visible and Invisible Light

Electromagnetic energy from anywhere in the solar spectrum will heat a surface, but the intensity and energy from the different wavelengths are not equal at all wavelengths. Roughly 44% of the sun's radiant energy is received by the earth in the form of visible light. Invisible light in the form of infrared solar energy accounts for another 53%, with ultraviolet radiation making up the final 3%. Other references may show slight differences in these percentages due to different standard setting bodies setting different wavelength cut-off points for UV, Visible, and IR radiation. Figure 1.5 below illustrates the radiation intensity in each wavelength range throughout the solar spectrum.

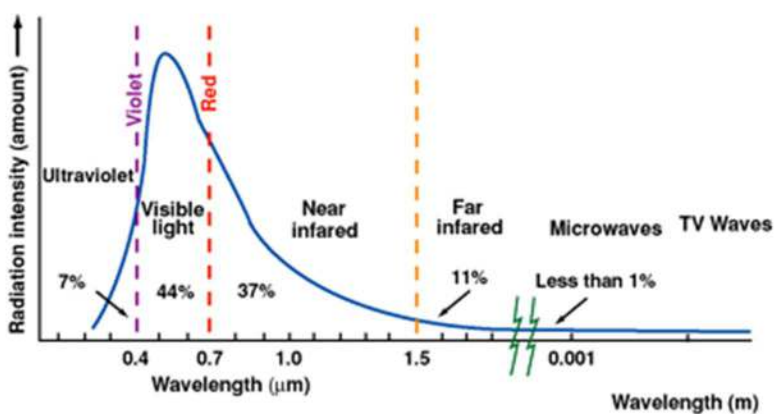


Figure 1.5

Other Forms of Heat Transfer

While it is important to understand the various forms of the sun's electromagnetic energy, it is also important to understand how heat transfer works. There are three forms of heat transfer: radiation (discussed in the previous sections), conduction, and convection.

Conduction

Conduction transfers heat within an object or between two bodies that are in contact. It is a point-by-point process of heat transfer. Conduction can occur in solids, liquids, or gases that are at rest.

Consider a cup of coffee. Using a microwave oven heats the coffee with microwave radiation. Conduction is the transfer of heat from the cup to the tabletop when the cup sits in contact with the table. Conduction is also what warms not only the cup but also the air immediately adjacent to the cup and the warmth felt when hands are placed around the cup without touching it.

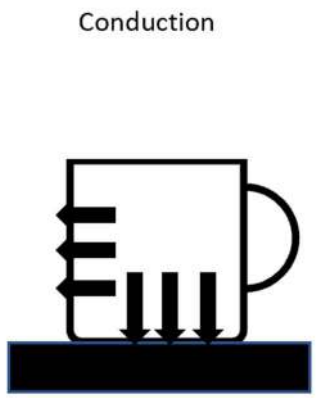


Figure 1.6

Convection

Convection is the transfer of energy in a liquid or gas due to the motion of that fluid. The motion may be natural or forced.

Natural convection: Using the coffee cup example once again, natural convection occurs when the coffee cup is in a room with a cooler temperature than the coffee. As the surrounding air warms through conduction from the cup, the air expands pulling new cooler air in and creating a cycle in which cooler air is warmed, expands, and continues to pull in cooler air. The transfer of heat through this natural air movement process is natural convection.

Forced convection: Providing an outside force which moves the gas or liquid faster than would occur naturally. In the coffee cup example, blowing over the surface of the cup is forced convection.

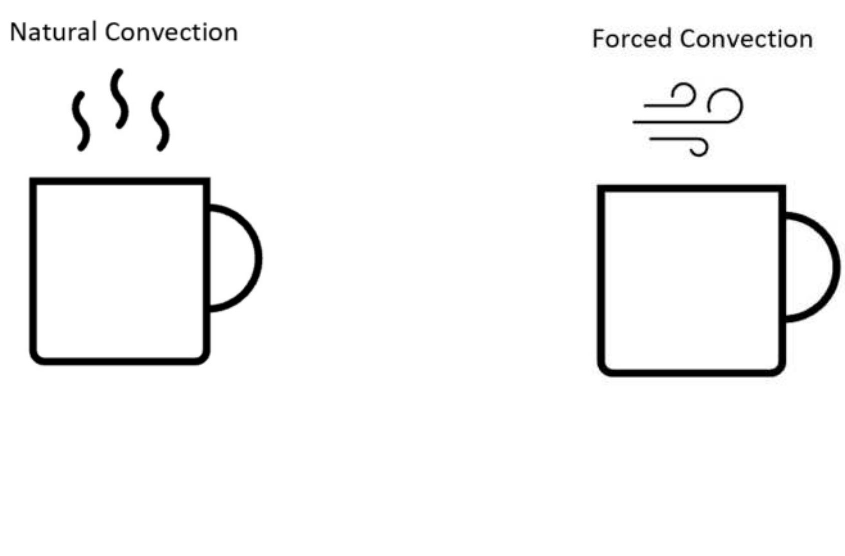
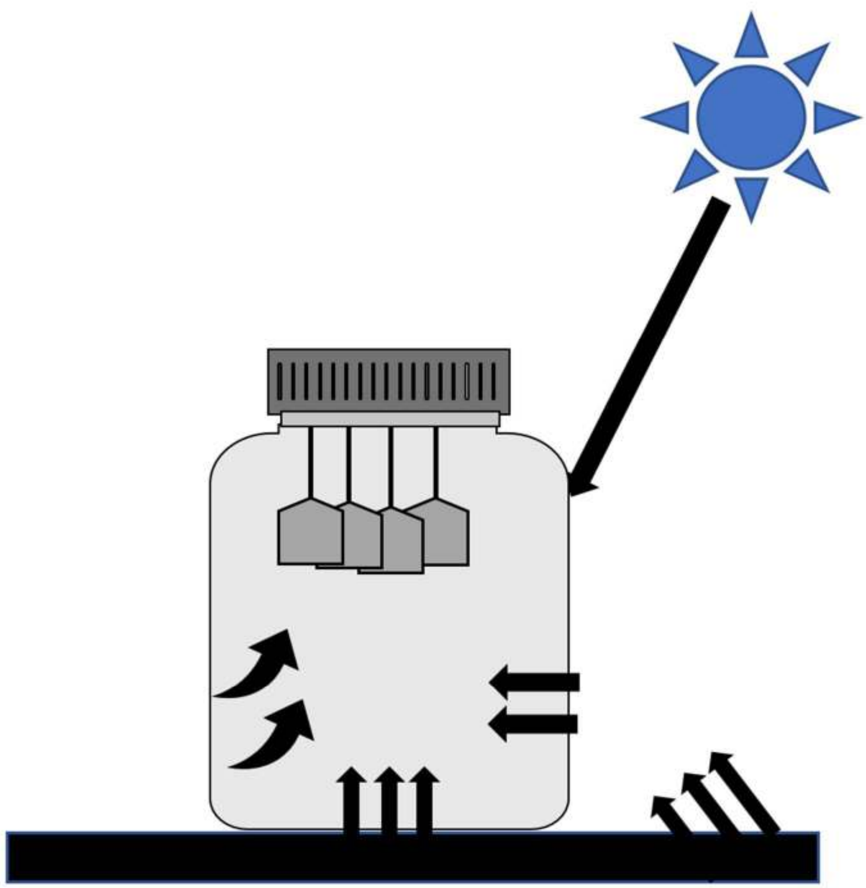


Figure 1.7

In radiation, conduction, and convection, the larger the temperature differences between the warmer body and the cooler body, the faster the heat transfer occurs.

Thermal Equilibrium

Heat energy flows from a high temperature to a lower temperature. When these temperatures balance, heat stops flowing, and the system is said to be in thermal equilibrium. In the case of the coffee cup, once the temperature of the coffee reaches the temperature of the room, heat transfer stops. In a closed system where the input energy continues, however, heat transfer can easily change directions. A closed jar of cool water placed in the sun will absorb radiant energy from the sun. If the contact surface and outdoor temperature are warmer than the jar and liquid, then energy from radiation, conduction, and convection are all flowing towards the jar and the air around the jar, as is shown in Figure 1.8 below.



Water Temperature less than outside temperature and surface temperature

Figure 1.8

Once the temperature of the liquid inside the jar and the jar itself are warmer than the outside temperature and the contact surface, the heat transfer from conduction and convection will change directions. The radiant heat transfer from the sun's rays continues to heat the liquid to the point at which the radiant energy cannot heat the liquid further than the conduction and convection cool it due to temperature differences.

Please reference Figure 1.9 below.

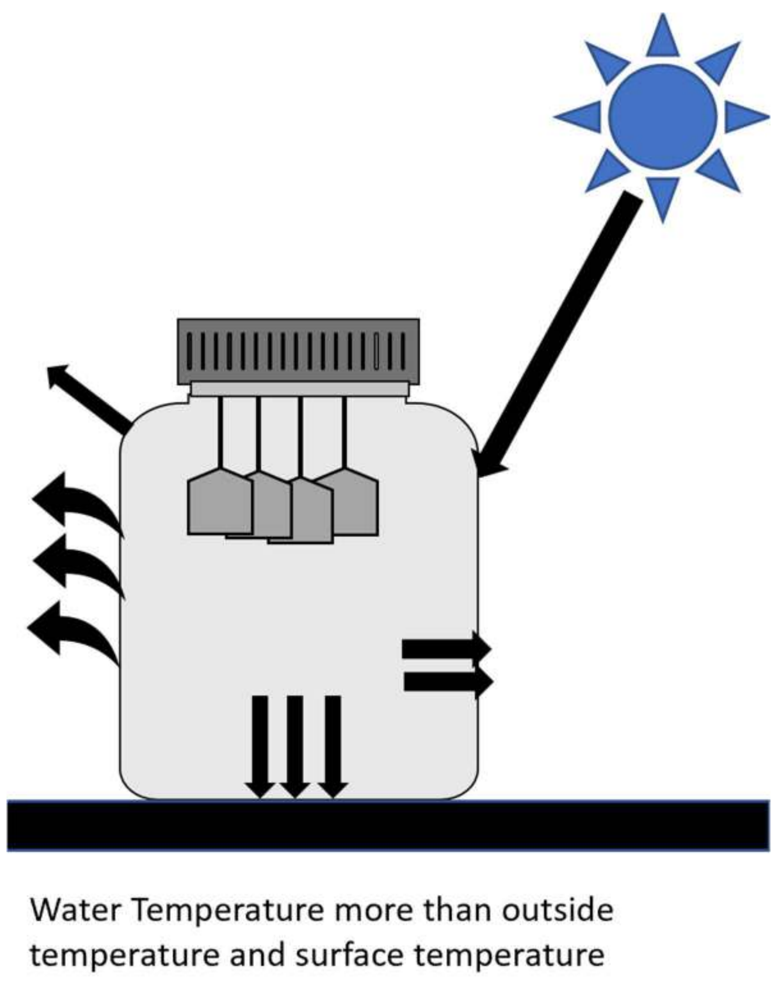


Figure 1.9

What Happens when Sunlight Strikes Glass

When sunlight (incidental solar radiation) strikes glass, three things can happen:

1. The energy can be reflected away from the glass.
2. The energy can be absorbed by the glass.
3. The energy can pass through the glass.

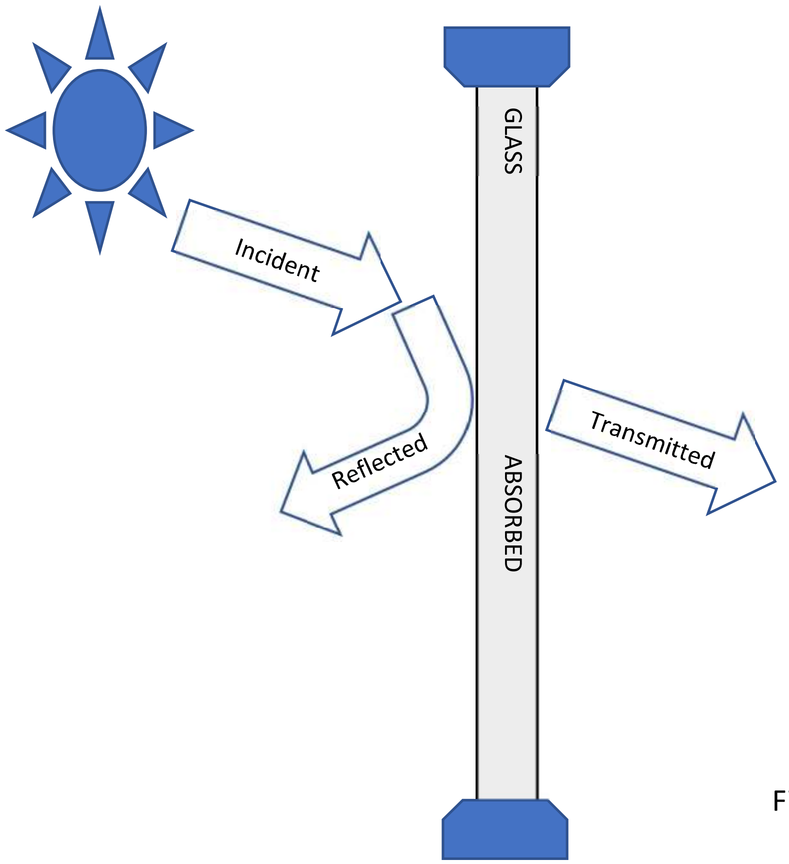


Figure 1.10

The performance definition for each of these events is expressed as a percentage, which will total 100%. Let's see what happens when sunlight strikes clear 1/8" glass.

Total Solar Reflectance	=	8%
Total Solar Absorptance	=	9%
Total Solar Transmittance	=	83%

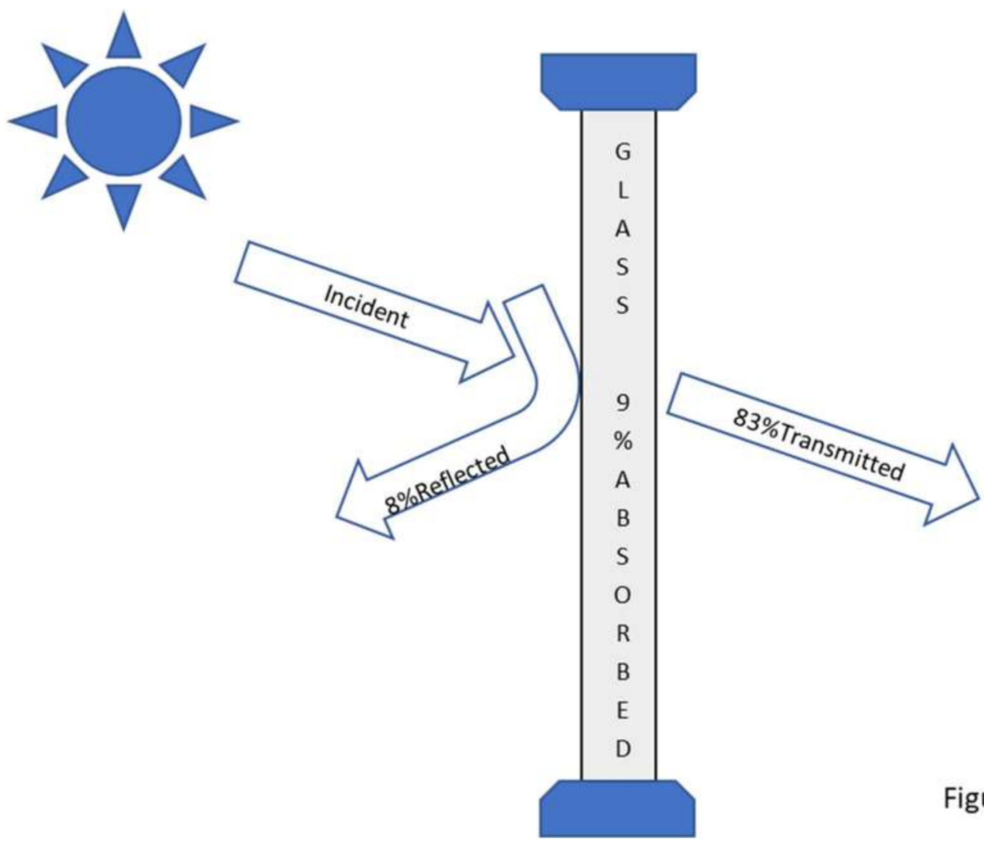


Figure 1.11

One of the easiest ways to remember this equation is using the acronym RAT. The sum of the Reflectance (R), Absorptance (A), and the Transmittance (T) must always equal 100%. If the values on a specification sheet do not equal 100%, then the manufacturer should be contacted. One percentage point in either direction may just be a rounding issue. If the variation from 100% is more than 1%, then the data should be considered suspect.

Let’s explore next what happens after the sunlight strikes the glass and heat transfer occurs.

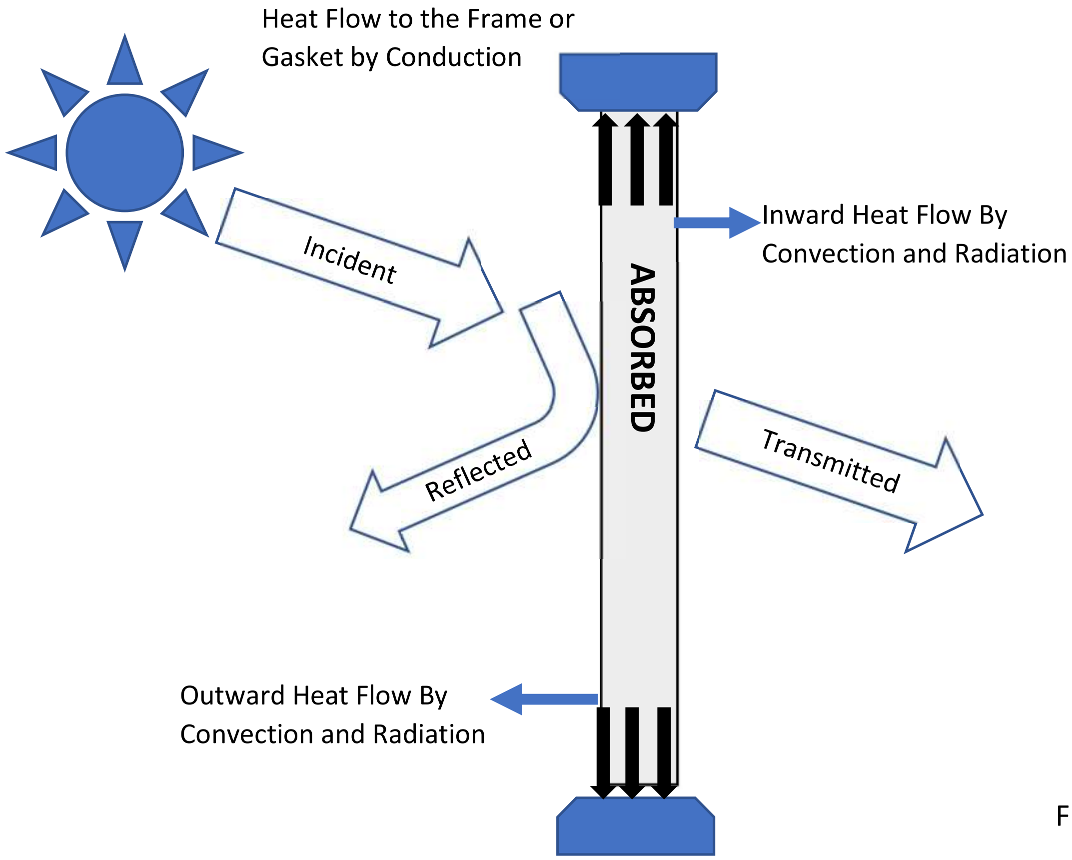


Figure 1.12

The solar energy is reflected, absorbed, or transmitted. The reflected energy does not enter the vehicle, and the transmitted energy goes through the glass without stopping. The absorbed energy flow is more complicated, with absorbed energy flowing inward or outward or both, depending on the temperature difference from inside to outside. This heat transfer happens through convection and re-radiation. The absorbed energy can also flow to the gasket or window mechanism through conduction.

Heat Transfer of Absorbed Energy in Glass

While transmittance and reflectance are fairly easy concepts to grasp, solar absorptance is more complex. As seen in Figure 1.12, the absorbed energy is partially transmitted through radiation. Absorbed solar energy is said to be “re-radiated” is this case. This refers to the fact that the transfer of energy occurs at different wavelengths than the source energy. While solar energy absorbed is from Ultraviolet, Visible, and Near-IR wavelengths, it radiates away from the glass as Far-IR wavelengths. In the glass jar example, the jar and its contents are heated by near-IR from the sun, but the increase in temperature underneath the jar is re-radiated Far-IR.

Figure 1.13 illustrates the heat transfer of absorbed energy of a parked vehicle where the outdoor temperature is cooler than the indoor temperature. Re-radiation is a surface phenomenon. As all heat transfer is from hot to cold, the radiation from the glass will occur at different speeds depending on the outside and inside temperatures. Figure 1.14 illustrates the additional convection that occurs when the vehicle is moving. Convection is measured using a standard wind speed, but when a vehicle is moving the speed of the air is significantly higher than the average speed of the wind.

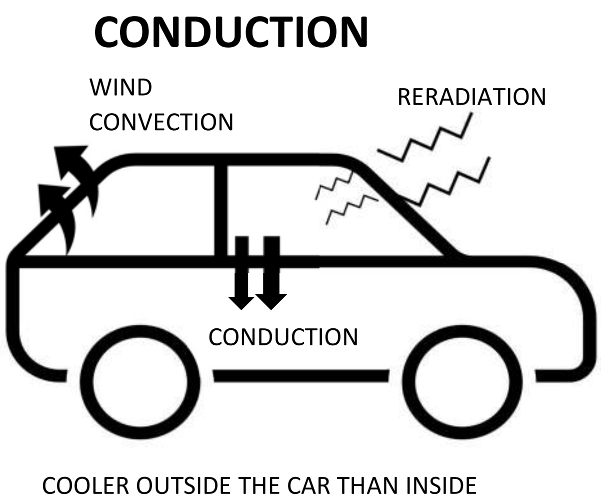


Figure 1.13

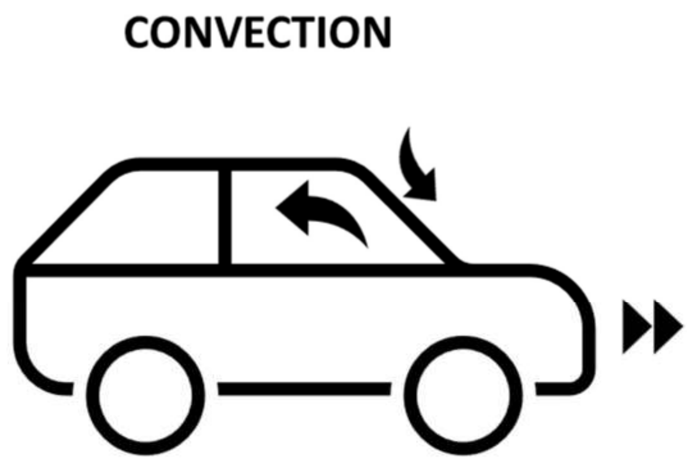


Figure 1.14

Review of Solar Terms

Below are short definitions of many of the terms introduced in this section. Remember to keep in mind the differences between the individual wavelength ranges of the electromagnetic spectrum. Some definitions refer to specific ranges within the solar spectrum, while others refer to the complete solar spectrum. In this section the glass used in the examples was clear, single-pane, 1/8" glass. The next section will give a brief history of glass and then explain differences in glass types, thicknesses, and coatings. In addition, the section will explain window systems.

Total Solar Reflectance (TSR)

The percent of incident solar radiation that is reflected by a glazing system.

Total Solar Absorptance (TSA)

The percent of incident solar radiation that is absorbed by a glazing system.

Total Solar Transmittance (TST)

The percent of incident solar radiation that is transmitted (passes directly through) a glazing system.

Visible Light Transmission (VLT)

The percent of visible light that is transmitted (passes through) a glazing system.

Visible Light Reflectance (VLR)

The percent of visible light that is reflected by a glazing system.

Ultraviolet Transmittance (UVT)

The percent of ultraviolet radiation that is transmitted through a glazing system. Many people prefer to report the percent of ultraviolet radiation that is prevented from passing through the glazing system for ease of customer understanding, but the actual measurement is UVT.

Infrared Transmittance (IRT)

The percentage of infrared radiation that passes through a glazing system. As with UVT, many people prefer to report a value that is the percent of IR that is prevented from passing through a glazing system, but this is more problematic in the case of IR, since there is a high degree of absorption, and the wavelength range is large and highly variable by wavelength in solar intensity. Calculations for a more accurate performance value will be discussed later in this guide.

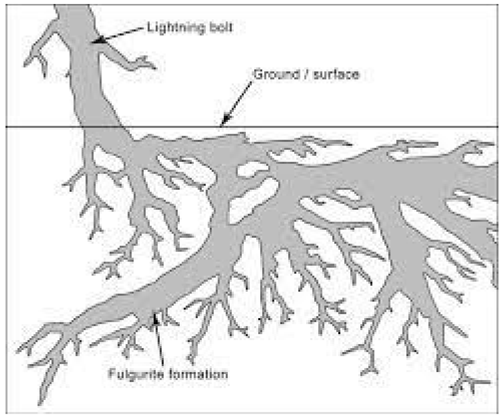
Section II: Glass and Glazing Systems

History of Glass

Glass may be one of the oldest known man-made materials, with examples of glass found at historic sites dating back to 7000 BC. By 3000 BC, glass was being used on a regular basis in Egypt but primarily for decorative purposes. It was another 1500 years before the art of making glass into useable shapes was perfected. The New York Metropolitan Museum showcases a vase believed to have been made around 1490 BC.

In simple terms, glass is liquid sand reformed into a transparent “solid.” The process requires heating the quartz sand, also known as silica sand, to temperatures above 3090 degrees Fahrenheit until it melts into a clear liquid.

The idea for making glass from sand may have had its origins from the natural occurrence of fulgurites. Fulgurites are tubes or crusts of glass formed when lighting strikes sand high in silica content and fuses the silica into a shape that mimics the path the lightning bolt travels through the sand.



Unlike the movies suggest, fulgurite doesn't look like glass but more like a sand encrusted piece of driftwood. Interestingly, fulgurites tend to be hollow, and these hollow tubes when exposed to bright light can be somewhat transparent.

Given the high temperatures needed to create glass, it is not surprising that glass took centuries to perfect. Glass blowing, which was believed to have originated in Phoenicia around 50 BC, greatly improved the possible uses for glass. Hollow objects such as glasses and urns are produced by "catching" a glob of molten glass on the end of a long hollow tube and then blowing air into the molten glass to form a bubble in the middle. The glass is rolled and manipulated at the same time to keep the molten glass from slumping to one side. The Venetians became masters at glass making, finding additives to give more flexibility in the manufacturing process and introduce color to the glass. Still, glass making remained more of an art form than a production process. The first "window" glass was made by catching a glob of glass, spinning it to increase the circumference, and then pressing it against a flat surface to make a circular sheet of glass. While the glass was roughly uniform in thickness, it was certainly flatter on one side than the other, and the spinning produced concentric circles visible in the glass and a dimple in the center where the glass was removed from the blowing tube. The circular glass was then cut into a square or rectangular shape to be used as a windowpane. The air bubbles, uneven texture, and general poor clarity made it difficult to see clearly through the glass, but it did provide light transmission.

The French perfected this type of glass by grinding and polishing the glass to improve clarity and thickness. The best of these became known as "French Panes," a term used to this day to describe small lites of glass even though they are no longer made with this process.

Modern Glass

Glass making and specifically, glass blowing, remained an art, and the industry was controlled by a small group of craftsmen motivated to keep the production of glass small and the skill required to produce it in high demand.

This all changed in 1916 when Michael J. Owens mechanized the production of glass containers and perfected the first machine for flat drawn window glass. In 1955, manufacturing took another leap forward when Pilkington introduced the float glass manufacturing method. Today, all automotive glass starts its journey as float glass.

History of Automotive Glass

The earliest motor vehicles were completely without windshields or side windows. As the speed of the vehicles increased, the windscreen became necessary and was introduced around 1900. The first windshields were made of sheet glass (> .0006" but < .25") and later switched to plate glass (.25" or more) for better optics. The original side and rear glazing were clear plastic. By 1910 the windshield became standard equipment in all motor vehicles. By the later 1920's almost all vehicles had wrap-around glazing. When sheet or plate glass broke in vehicle crashes, it shattered into dangerous shards which caused severe injuries in many cases. It was estimated that almost 50% of injuries in accidents was caused by broken glass.

Types of Glass

Glass can be categorized by the amount of heat used in the manufacturing process, namely hot, hotter, and hottest. At the low end of the scale is annealed glass, followed by heat-treated glass, and finally tempered glass. All three types of glass start as annealed glass, but heat-treated and tempered glass are subjected to subsequent processes which change their breakage characteristics. Annealed glass can be cut at a glass shop, but heat-strengthened and tempered glass must be heat treated at the size they will be used as they cannot be cut to size after heat treatment.

Annealed Float Glass

The most common window glass available on the market is commonly referred to as annealed float glass or simple annealed glass. Annealed float glass is manufactured in a process where molten glass is poured continuously onto a bed of molten tin. The molten glass tends to seek a level configuration as it floats on the surface of the molten tin. The thickness of the glass is relative to the rate at which the molten glass flows from the tank onto the tin. If the flow rate is slowed down, the glass is thicker. Because the melting point of the tin is much less than that for the glass, the glass solidifies as it cools on top of the tin. Once the glass solidifies, it is fed into an annealing oven where it is slowly cooled so that the residual stresses are minimized. This process results in the production of a glass product, which is very flat with nearly parallel surfaces.

Since annealed glass has a minimum amount of residual surface compression, it is subject to easy breakage. Annealed glass is the most fragile of all manufactured glass. It is subject to breakage from airborne flying objects, human impact, and thermal stress fracture as a result of temperature changes.

When annealed glass breaks, it does so in many sharp, irregular-shaped pieces referred to as shards. Depending on the cause of the glass breakage, these jagged pieces of glass can be propelled at high speeds and can cause serious bodily injuries and even death.

Heat Strengthened Glass

A slightly stronger glass can be produced by applying heat to annealed glass after the float process. The glass still breaks into shards but takes more force or temperature differences to break. Because of the ease of breakage and the risk of injury, neither annealed nor heat strengthened glass are used in vehicle production.

Tempered Glass

Tempered glass is a type of glass that is the result of heating and rapid cooling to induce a change in structure leading to an increase in strength. Single sheets of annealed glass are heated to temperatures around 1200°F. This is the temperature at which annealed glass begins to soften. The outer surfaces of the glass are then rapidly cooled. This creates high compression in the surfaces.

This type of glass is about four times stronger than regular annealed glass. The change in structure has two main benefits. First, the glass is much stronger, and second, when the glass is broken it breaks into small, rounded fragments as opposed to the large, sharp, shards created by annealed glass. This is the major reason that tempered glass is used in almost all vehicle windows except for the windscreen (windshield).

There is another great benefit to tempered glass. It is very resistant to cracking from the thermal stress caused by solar absorption and temperature differentials from edge to center of glass. Vehicle glass is not susceptible to most glass breakage other than impact.

How to Identify Glass Types

Tempered glass products are identified through a clearly visible corner etching stating that the glass complies with safety glazing standards. The presence of this marking is intended to assure that the glass is fully tempered. All vehicles will have the glass manufacturer and glass type clearly identified in the corner of each window. The high compression strength of tempered glass also leads to the rainbow of colors and some of the “circle” patterns visible in vehicle glass when viewed with polarized sunglasses.

Glass Constructions

For the purposes of this training guide, glass constructions can be divided into two major categories:

Monolithic

Laminated

Monolithic

Monolithic glass is the simplest glass construction type. It consists of a single flat piece of glass of constant thickness. Virtually all monolithic glass produced throughout the world today is produced using the float glass method. Most auto glass used today is ¼" or 6mm minimal thickness.

Figure 2.1

Laminated Glass

Laminated glass is produced using two or more monolithic layers of glass permanently bonded together using an "interlayer." The first automotive safety glazing was laminated glass used in France in the early 1900s. That product consisted of a layer of gel sandwiched between the two pieces of glass. While the gels varied in make-up, they all discolored, developed cracks over time, and often delaminated. Henry Ford introduced laminated windscreens in the 1927 Model T Ford. The most common interlayer is polyvinyl butyral (PVB). It was introduced in 1933 and was a far superior product to the gel products. Advanced versions of PVB are still being used today in almost every vehicle on the road. Most laminated glass layers used in vehicles is annealed glass.

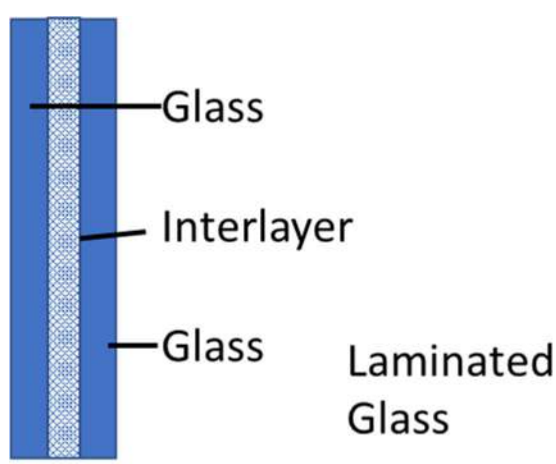


Figure 2.2

Laminated glass is designed to be used in areas where increased strength, impact resistance, noise reduction, or flying glass may cause serious injury. Laminated glass is specified in almost all countries as the glass used in windscreens. It is also sometimes used in high-end vehicle side windows for noise reduction and sometimes found in sunroofs. As with all auto glass, the etched information in the corner of each window will indicate the glass type.

Non-Clear Glass

Tinted Glass

All automotive glass is tinted to some extent. The color is added into the glass in a process called a full-bodied coloration process. In this process, the color is mixed in with the glass at the time of manufacture, resulting in a glass that is colored consistently throughout its thickness. Additionally, laminated glass can be colored by using a colored PVB instead of coloring the actual glass. Vehicle glass is generally some version of green, blue, or charcoal.

Regional laws exist that determine the amount of tinting allowed on various parts of the vehicle. In most countries, the windscreen and the driver/passenger windows are above 70-75% VLT. The laws around side, rear, and back glass vary widely between countries, regions or states. Tinted glass is used in vehicles for improved heat reduction and for privacy. These glass types do not normally have any additional UV protection, so the use of film is still very beneficial.

Performance Glass Coatings

Glass that has metallic or metallic oxide coatings applied onto the surface is generally known as reflective coated glass. Unlike architectural glass, automotive glass must meet regional standards around reflectivity for driver safety. Glass with an obvious reflective look is only found on the rear and back windows of SUV's in most countries.

Additionally, metallic and metallic oxide coatings can be applied in combination yielding high performance glass coatings.

Spectrally selective sputter coatings are produced using a combination of metal and metal oxide coatings and have the distinction of producing glazing products with a combination of high visible light transmission and low visible reflectivity but high solar reflectivity.

Spectrally selective IR-absorbing coatings are produced using nanoparticles incorporated into the PVB layer of laminated glass. They have high visible light transmission and low reflectivity as well although, because they work through absorption of energy and not reflection, they are slightly less efficient than the metal oxide versions. However, they are generally slightly less expensive to manufacture and less likely to corrode than the sputter coatings.

Both coatings must be protected and are found almost exclusively with a laminated glass structure. For that reason, these high-performance windows are used in window screens and only on the side and rear windows when used in luxury vehicles.

Dynamic Coatings

Dynamic coatings are those that change solar performance in some manner based on an input. There are three general types of dynamic coatings and several variations within those types.

Thermochromic – Coatings that change solar performance properties with temperature.

Electrochromic – Coatings that change solar performance properties with electric stimulus.

Photochromic – Coatings that change solar performance properties with light stimulus.

Functional Coatings

Ceramic frit coatings are the black coating found on the edge of the glass which is designed to protect the interior gasket materials from sun deterioration. Windscreen and rear glass are installed in the vehicle from the outside and often the glass is bigger than the vision area viewed from the interior. These screen-printed coatings are often rough or contain release agents left from the glass molding process. They are commonly called “dot matrix” coatings.

Defroster wires are found on the rear windows of many vehicles. These allow the driver to flip a switch and run a low current through the wires, warming the glass enough to defrost or de-ice the rear window. While other coatings such as the ceramic frit are fired after coating, which makes them very hard to scratch or remove, defroster wires are very easily disrupted, and care must be taken when interacting with these coatings.

Heads up Display or HUD coatings are starting to be seen in vehicles. These coatings have actual driving functionality. Heads up Displays or HUDs are becoming more common on the front windscreen and allow the driver to see certain dash outputs such as the vehicle speed without looking away from the road.

Framing Systems and Glazing Materials

Gaskets, sealants, and tapes are used to provide an effective seal, cushion the glass, and provide thermal insulation between the glass and frame.

Window gaskets are lengths of rubber that place a secure seal between a glass and a body panel. Although these can be made from a variety of different materials, gaskets made from Ethylene Propylene Diene Monomer (EPDM), a synthetic rubber, are one of the most common types. They need to be resistant to the elements but still able to maintain elasticity and hardness properties. Sealants may be used individually or may be combined with weatherstripping.

Weatherstripping is a rubber material that seals the edges of a vehicle's doors, windows, and other areas. It prevents outside elements such as rain, snow, wind, and pests from reaching the inside of the vehicle.

Automotive windows can be contained within a frame or can be considered "frameless." Standard side windows slide up and down within the frame while frameless windows are only in contact with the side and top gaskets when the doors are closed.

Important consideration is made to ensure the framing that supports the bottom of a moveable window is very secure and that the interior gaskets (also sometimes referred to as the rub-rail) are tight enough to keep out the exterior environment but not so tight as to make movement of the window glass difficult.

The Evolution of Automotive Glazing

Automotive glazing has come a long way in the last hundred years. Tempered and laminated glass were gaining ground at the same time specifically for their improved safety characteristics. Tempered glass was first used in motor vehicles starting around the same time PVB laminated glass was introduced in the early 1930's. In Europe it was used throughout the vehicle including the windscreen. Gradually the U.S. manufacturers moved to tempered glass on the sides and rear, while European manufacturers moved to the safer laminated glass for windscreens. By the early 1960's only the windscreen was laminated glass, and it remains so for most vehicles today.

Air conditioning was introduced in the 1940 Packard. When it was turned on, the demand on the power train caused the vehicles to slow down significantly. The glass manufacturers responded by introducing tinted glass. By the end of the decade, all the car manufacturers offered vehicles with air-conditioning and tinted glass as options.

At the same time, the curved windscreen and rear glass were introduced to help improve the styling of the cars. With no restrictions or concerns on fuel efficiency, automotive vehicles increased in size and the styling complexity required production of compound-curved laminated windscreens. Curved windscreens were the norm by the mid-1950's, with some of the windscreens being a whopping 80" wide.

As shown in the previous sections, glass has continued to evolve to meet new requirements, and the automotive glass of today often has significant technology incorporated within it. Edge frit to protect the sealants, glass coatings for improved solar control, incorporated antennas, frost removal systems, and heads up display technology have all made their way into the windscreen or other areas of the vehicle.

But what about other types of glazing?

<u>Polycarbonate Glazing</u> or plastic glazing has found some limited use in vehicles. Currently plastic glazing used by itself is only allowed in non-passenger safety areas of vehicles, so it is found in

some cargo vans or hearses. Laminated glass containing a layer of polycarbonate along with the glass is used for bullet resistant glazing. This glazing is specifically manufactured to protect high-profile passengers from attack and needs to be installed in specifically designed framing. This type of glazing is heavy and thick.

Solar Control Window Film

Introduction

One of the major contributors to automotive passenger discomfort is the heat and glare associated with large glass areas. People have resorted to all sorts of devices to block the heat and glare coming in through the glass. Often these solutions resulted in a reduction in visibility for the driver and were not ideal. Sunglasses and visors help with the glare but do little to reduce the heat felt in the vehicle. Since the first window films were for architectural use, people tried using those films in cars, but they were often too dark and too reflective to be a good solution. As manufacturers realized this was a burgeoning market for auto film, specific films were designed and manufactured. When automotive window film was first introduced in the market, it experienced wide acceptance in the sunbelt states, as it was finally a better solution to the problems than earlier ideas.

The first films offered were non-reflective, which reduced glare and heat gain to some extent primarily because they worked by absorbing solar energy. While these films were limited in their functionality, they did a great deal to improve the appearance of the car. The appearance factor became the driving force for the market, but it became obvious the market could grow substantially if the functionality of the films could be improved. This functionality factor was first addressed by the advent of higher-performing films, which used a metallized film layer which was lighter than used in architectural but still capable of improving heat rejection. This metal film was combined with a dyed film to lower the reflectivity even further to give the appearance factor that was still very important. Today a wide range of films are produced for a wide range of global markets and are installed in a wide variety of climates.

Product Benefits

Automotive window films possess numerous consumer benefits. These benefits exist to a larger or lesser extent depending on the design of the film. The major benefits include:

- Improved Exterior Vehicle Appearance
- Solar Heat Reduction
- Ultra-Violet Protection
- Glare Control
- Safety

Some of these will be discussed in more detail at the end of this section, but a brief review is provided below.

Improved Appearance

The appearance of a vehicle is improved after the application of film, because the car will look "more balanced" aesthetically. The normal separation between the roofline and the body tends to blend rather than appear as a stark separation found with clear glass or the very light factory tint. The use of film can also remove the jarring side-view visual difference in trucks and sport utility vehicles between the dark factory-tinted back glass and the very light front windows. It also masks protuberances normally seen such as the headrests, seat tops, and steering wheel. This balancing of the appearance also allows for a certain amount of privacy for the driver, passengers, or vehicle contents. Depending on the light transmission, this can be an important benefit for some consumers.

Solar Heat Control

As previously discussed, solar heat control can be achieved in two ways – it can be absorbed or reflected. While reflecting products are generally more efficient, this is less evident when the car is moving. The improved efficiency of reflecting films is more evident when the car is sitting still, although at some point the vehicle and the outside air reach equilibrium. Reducing heat is not only important to the comfort of the driver; it is also a significant factor in reducing the degradation of many plastic parts found in automobiles. These plastic parts may last longer than otherwise, since they will not be subjected to the same amount of direct heat of the sun as they would without the application of film. This is most obvious on the dash, but not all regions allow installation of film on the front windscreen, so always follow the applicable regulations for the area. Remember, the larger the glass area, the bigger the impact.

Ultra-Violet (UV) Radiation Control

Control of ultraviolet radiation is important for two reasons in vehicles. Many people spend significant hours in their vehicles every day, and the effects of UV radiation on the skin and eyes is cumulative. Additionally, a vehicle's interior fabrics and panels are susceptible to fading, and window film can help reduce fading and deterioration due to UV radiation. Both of these benefits will be discussed in more detail in the next section.

Glare Control

The ability of automotive window film to reduce glare may be the most beneficial of all the properties of the product. Glare comes from too much visible light causing eyestrain and discomfort.

Safety

In addition to window film's added protection of skin and eyes from harmful ultraviolet rays, the installation of safety film on automotive glazings can provide a number of benefits. When properly installed, safety film forms an almost invisible protective coating on the interior side of the glass surface. If glass is then broken due to an automotive accident or attempted forced entry, the film can stretch and absorb some or all energy generated by the stress. The broken glass may remain intact within the framing system, preventing or reducing human injury. While most automotive glass other than windscreens and some higher-end vehicle windows are produced from tempered glass, even broken tempered glass can cause injury, and potential personal injury can be significantly reduced with the use of safety film. More in-depth information about safety film is outside the scope of this guide. To learn more about this subject, please refer to the Safety & Security Education Guide.

The rest of this section will focus on the basic building blocks of window films, how those layers are manufactured, basic window film structures, and the measurements and industry standards used to describe window film performance.

Basic Window Film Manufacturing Principles

Window film is produced in what is termed a “conversion process.” This term applies to the process by which several different layers and raw materials are combined or “converted” into one cohesive final product. There are several raw materials used in the final structure, and they may include raw polyester film, dyed polyester, metal, or metal oxide/nitride coated polyester, various performance coatings, and liner material. How these raw materials are combined or “converted” will determine the type of window film produced. No matter what the final combination, they all will require the addition of a scratch-resistant coating and an installation adhesive.

The five basic processes used in the production of window film are:

Dyeing or coloring film

Vacuum Deposition (electron beam, metallizing, sputtering)

Laminating

Coating

Slitting

Manufacturers of window film will possess the ability to perform some or all of these processes. To maintain the optical quality of the finished products, most of the processes will be performed in “cleanroom” environments. A cleanroom is simply a sealed-off area which has the incoming air filtered to remove impurities. These “rooms” are also kept at slight positive air pressure to prevent air contaminants from entering through openings. The personnel who work in cleanroom environments are required to wear special uniforms to prevent contamination. These processes are all very technical and must be tightly controlled to produce an acceptable product. While window film may look like a simple product, that is far from the truth.

Raw Materials

Polyester Film

Developed in the late 1920s and early 1930s, polyester film is a popular laminating substrate. Manufactured by melting polyester chips and then extruding and stretching the film length and then the width at high speeds, polyester film is a highly useful substrate. It is durable, chemical resistant, tough, highly flexible, absorbs little moisture, and has both high and low temperature resistances for superior dimensional stability. It offers crystal clarity and can be pre-treated to accept different types of coatings such as adhesives. Polyester film can also be metallized and easily laminated to other layers of film. It can be dyed, or it can be metallized by either vacuum coating or sputtering to produce an array of colored and spectrally selective films. Polyester film thickness is measured in the United States in "mils," which is .001 inches. In other parts of the world, this same film is measured in microns, with that same 1 mil film measuring 25 microns. Standard automotive window film widely uses 1 mil (25 micron) or ½ mil (12 micron) film. Polyethylene Terephthalate (PET) is one of the most common forms of polyester. Polyester film serves as the backbone for the window film industry.

Coatings and Coloration

Coloration processes

Color is imparted to the film in several ways. The color can be infused throughout the film either as part of coloring the PET chips before extrusion of the polyester into sheet form or deep dyed in an immersion process after the film is at its finished width and thickness. Additionally, the film can be surface coated and then the coated color infused into the polyester or surface coated and left on the surface as a standard coating. There are many positives and negatives to each of these processes which are outside the scope of this document.

Ultraviolet UV Absorbers

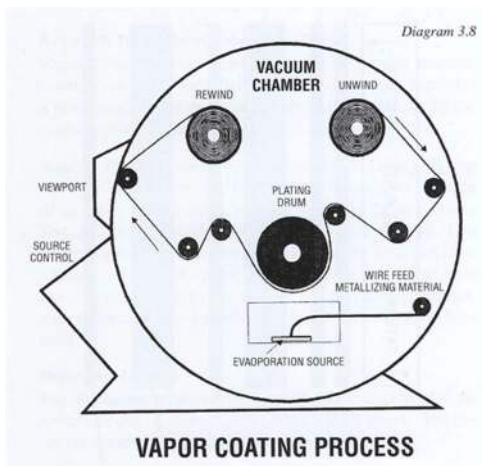
Special ultraviolet (UV) absorbers are utilized to prevent the sun's ultraviolet rays from breaking down the polyester film or adhesives that laminate the layers of polyester film together or bond the film to the glass. These UV absorbers can be present in either or both the adhesives, and/or it can be impregnated in the original polyester film. Absorbers allow window films to provide a significant degree of UV protection against the fading of automotive interiors and provide significant skin and eye protection to drivers and passengers.

Vacuum Deposition

Metals and other metal oxides or nitrides are coated onto polyester film through processes that run in a vacuum (negative air pressure). Collectively these are known as vacuum deposition processes. There are two basic deposition processes with some variations within those processes.

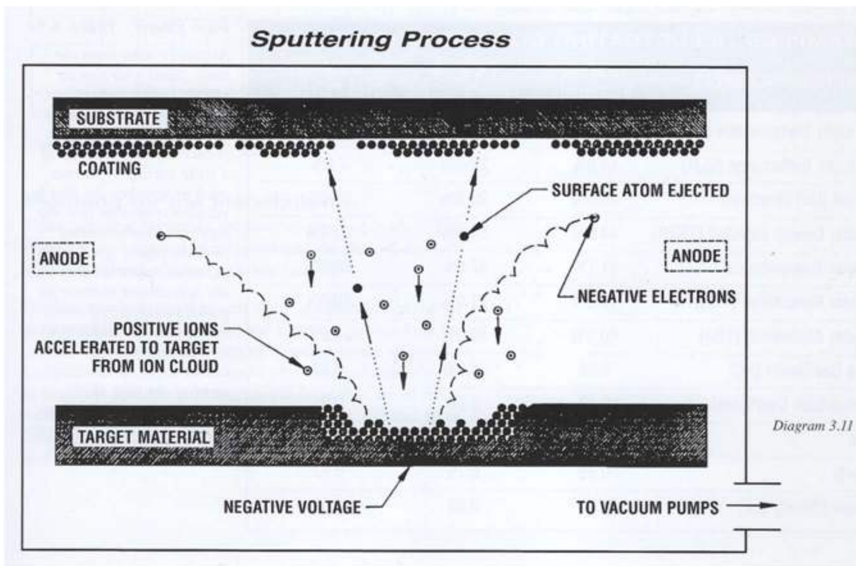
Metallizing

In simple terms, metallizing (or vapor deposition) is a process whereby a metal (almost exclusively aluminum) is applied as a coating onto clear film. Pure metal wire is continuously fed onto shallow electrically heated "boats." Because the chamber containing the film and the boats has been pumped down to a very low pressure, the metal wire turns from solid to liquid and then gas at a temperature much lower than would be required at standard atmospheric pressure. This gaseous aluminum rises out of the boat much like steam out of a teapot and converts back to a solid when it hits cooled polyester film moving at a high rate of speed over the boats. The thickness of the coating is controlled by a shutter mechanism, the power to the boats, and the speed of the process. The aluminum layer deposited on the surface of the film has a very "open" porous structure. Diagram 3.8 below shows the basic elements of a vapor deposition chamber. A newer version of metallizing uses similar principles but uses an electronic beam to convert the metal to gas and can be used on metals with higher boiling points than aluminum.



Sputtering

The basic sputtering process involves a large vacuum chamber and an inert (non-reactive) gas atmosphere as well as electrical energy. The electrical energy imparts a negative charge to the inert gas molecules. Because the atmospheric pressure is very low, the negatively-charged gas particles move freely and are attracted to the negative voltage underneath the material to be deposited. That material can be either in a solid flat plate or a cylindrical spinning roll, both called targets. When the negatively charged particles strike the target, they dislodge metal atoms which fly at high speeds to strike the film moving over the target. The cloud of highly charged particles found between the target and the film is called the “plasma”. This process allows the composition of the coatings on the film to match the composition of the target material almost exactly. If a non-inert gas like oxygen is introduced to this process, it will react with the metal atoms and form oxides, which will have very different properties than the original metal. Because this process involves physical deposition of the target material, it is often called a physical vapor deposition process (PVD). This allows metals with high melting points and alloys with varying melting metals to be deposited, something which would be impossible with standard vapor deposition.



Scratch Resistant Coating (SRC)

Manufacturers utilize numerous types of scratch resistant coatings applied to the exterior surface of the film to protect it from normal wear and tear and abuse by humans or by the natural environment. They will not protect the surface from gouges or abrasion from sharp objects or tools. Polyester film by itself is not scratch resistant.

Window films are normally tested to ASTM D1044-94, the Test for Resistance of Transparent Plastics to Surface Abrasion. This is often referred to as the Taber Abrader Test, as this is the equipment used to perform this test. This device repeatedly abrades the surface of the film, and after a certain number of cycles, it measures the amount of haze (scratching) created by the abrader mechanism. The difference in haze before and after the test is known as the haze delta.

Adhesives

Window film manufacturers have developed and utilized a variety of patented adhesive formulations to adhere their films to the glass (installation adhesives) and to laminate one or more layers of polyester film together (laminating adhesives).

Laminating Adhesives

Laminating adhesives are typically used to bond two or more layers of film together. These layers may in turn be laminated to form a final product. Laminating adhesives can be pressure sensitive with a high degree of tack or may be a cured adhesive, which makes a very permanent bond and would destroy the layers of film if they were pulled apart. The cured adhesive types tend to have a much lower coating thickness.

Installation Adhesive

Pressure sensitive adhesives are used primarily to apply automotive window films.

Films are installed using a soapy water or a proprietary solution sprayed on both the glass surface and the film adhesive surface after the protective liner has been removed.

Pressure sensitive adhesives form a “flat” mechanical bond with the surface of the glass based on pressure between film and glass.

Performance Coatings

IR Nanoparticle Coatings

Many manufacturers have developed special performance coatings that impart solar properties. Some of the most common coatings combine infrared absorbing particles with an adhesive or UV cured coating. These coatings may be incorporated into the scratch coating, laminating adhesive, installation adhesive, or may be coated as a separate layer. There are pros and cons to each option, and discussions of those are outside the scope of this document. Please refer to the manufacturer for any questions concerning the placement of the coatings. There are also several different chemical structures for the IR nanoparticles, with each having a different color and degree of solar performance. All current nanoparticles solar coatings work predominantly through solar absorption and not solar reflectance.

Release Liners

The mounting adhesive of window films is protected by either silicone or silicone-coated release liners. The liners are removed in the installation process. Since release liners are eventually discarded, the films used will vary in haze. To view window film samples with the highest degree of optical clarity, the release liner should be removed prior to inspection. Even then, slight irregularities on the adhesive surface may appear as visual flaws but they may disappear after bonding to glass has occurred.

Basic Automotive Window Film Types and Structures

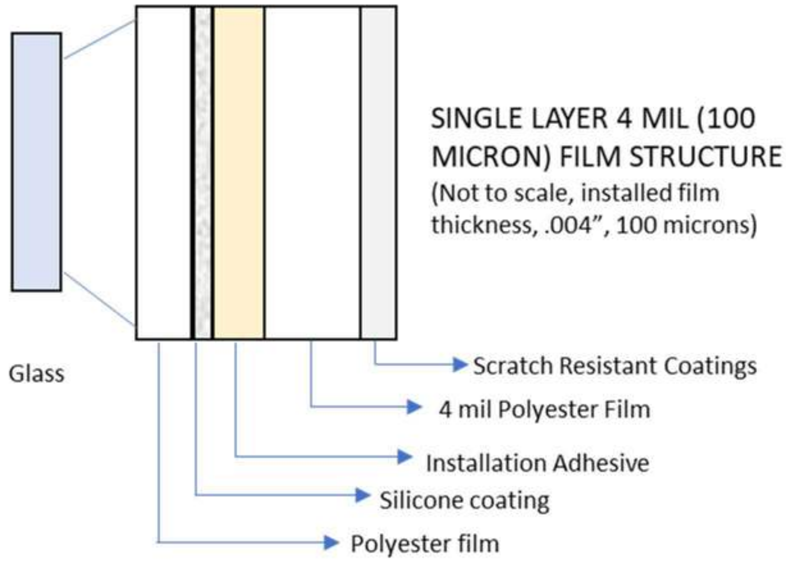
There are four basic categories of automotive window films:

1. Clear
2. Nanoceramics - IR absorbing coated films
3. Reflective – Metallized films
4. Sputtered films
    a. Neutral low reflectivity metals
    b. Metal Nitride Ceramics
    c. Spectrally Selective

Almost all window films are installed on the interior side of the vehicle glass. While these window film types may seem similar to architectural offerings, automotive films should not be substituted for architectural products without specific approval from the manufacturer.

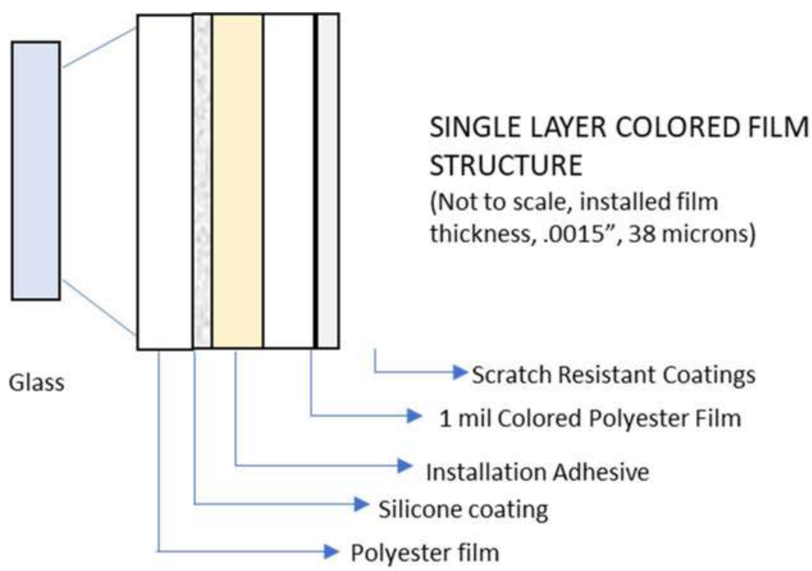
Clear Film

Most clear film products fall into the category of Safety and Security Films. These films offer safety protection and some UV control to reduce fading. Safety films are generally considered to be 4-mil and greater with thicker pressure sensitive adhesive layers to hold broken glass together after a glass breakage event. These films are considered non-reflective, since they do not contain any metals to reflect solar radiation. (Note: Some safety films can exhibit color when one or more layers are dyed, or metallized, and are laminated together.) There are some thin clear UV films available that are used in special medical exemption applications or where no other film can legally be installed on a particular window in a vehicle. The diagram below shows a standard clear 4 mil safety film structure.



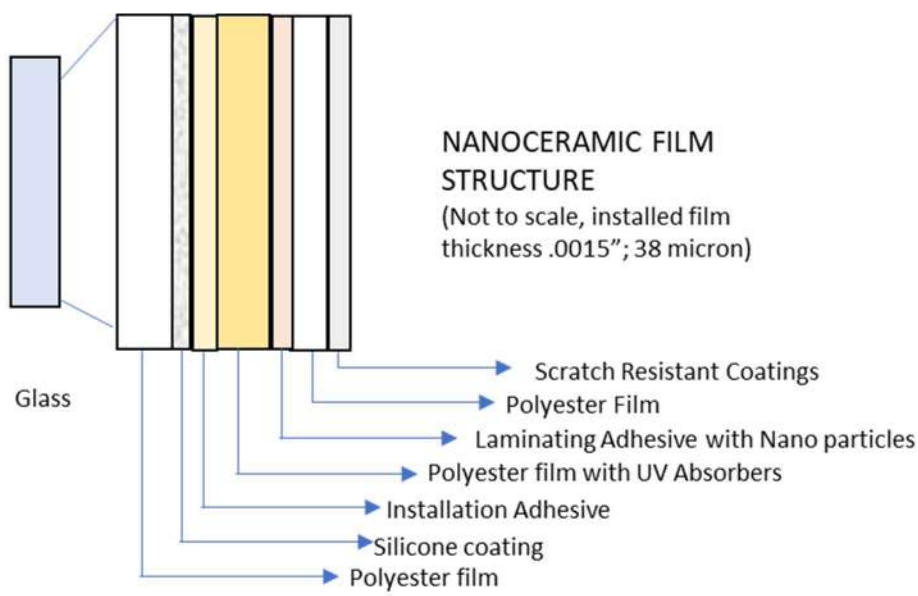
Colored films

Films that contain a coloration layer only are a significant portion of the global automotive market. These tend to be the entry level films which make them affordable for a wide range of consumers. They can provide improved appearance, privacy, glare protection, ultraviolet protection, and moderate heat gain protection. All of the rest of the films below will provide these basic benefits with the trade-offs being in light transmission, reflectivity, and solar performance.



Nanoceramic

These films contain no metals and are considered non-reflective. Based on their VLT, they can provide glare and fade protection and reduce heat gain by solar absorption. The films come in a variety of colors achieved by a combination of the IR absorbing nanoparticle and the other dyed or colored films used in the structure. As these films do not contain metal, they are often less effective in terms of solar control because all heat control occurs as the result of absorptance, which is less efficient than reflectance. However, they can be much higher in performance than standard colored films since the IR absorbing nanoparticles are much more efficient at absorption than dyes. The diagram below shows a 70% visible light transmission window film where the IR performance coating is part of the laminating adhesive. Most nanoceramic solar performance particles are not capable of producing a dark film using just the particles. The high visible light transmission of these films with relatively high solar absorption makes them good candidates for windscreens (where legally allowed) and other windows in regions with high VLT tint laws.



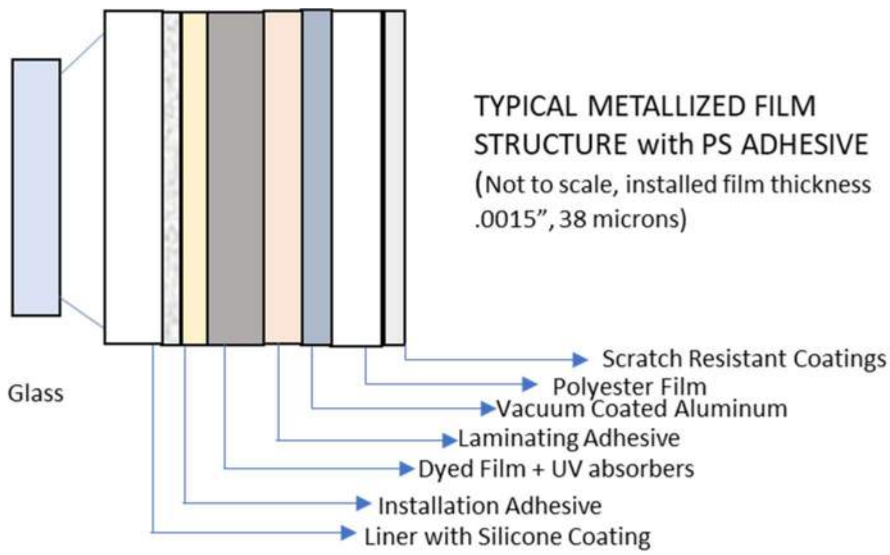
Vacuum Coated Films

Many films are manufactured using the previously described methods for depositing metals, oxides, and nitrides. These films have tremendous solar control properties because they can reflect significant amounts of solar radiation. They are traditionally identified as reflective, neutral, or sputtered films. There are new films that contain metal, metal oxides, metal nitrides or combinations but do not appear visually "reflective."

Reflective Films

Most reflective automotive films are combination vapor deposited aluminum and a coloration layer. These are often referred to as "hybrid" films or "high performance" films. As the vacuum metallizing process can be tightly controlled, the thickness of the aluminum layer can be manufactured to precise tolerances. The thicker the aluminum layer the lower the visible light transmission. In general, the lower the visible light transmittance, the higher the solar heat rejection and the higher the visible reflectance. The eye starts to perceive that something is "shiny" or reflective around 11% reflectivity, and many regions have laws restricting the allowed reflectivity for automotive films. Care must be taken to understand whether the law is referring to interior or exterior reflectivity. Exterior reflectivity is most obvious during the day with the sun shining on the outside of the car, but interior reflectivity is most obvious during the evening and in dark locations like parking garages.

The Diagram below shows a metallized film laminated to a colored film with a PS adhesive and silicone release liner.



Sputtered Films

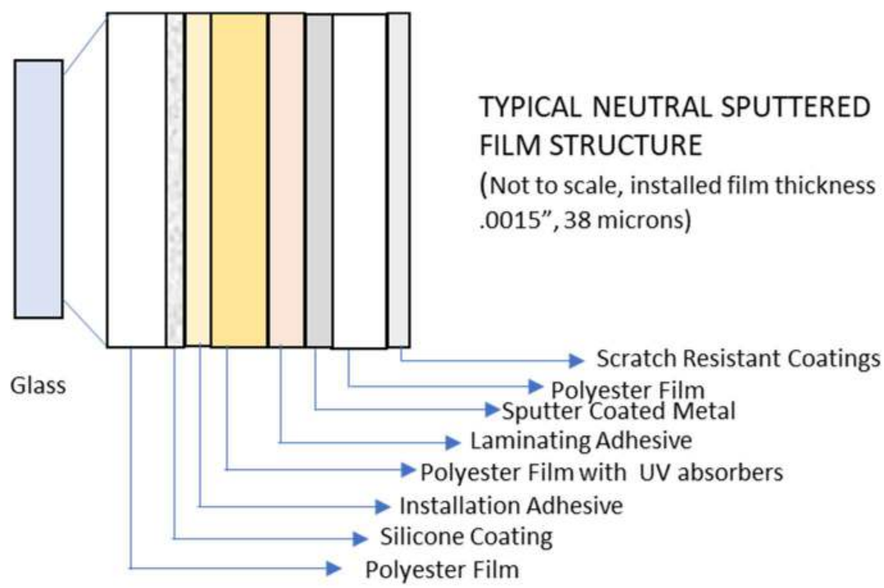
A layer of sputtered metal is deposited on the film in a more dense form than traditional metallizing, and as such, most sputtered films will be slower-drying unless the manufacturer goes through special steps to improve the porosity of the sputtered layer.

There are three types of sputtered films:

- Films featuring a metal or metal alloy, e.g. stainless steel, nickel-chromium, etc.
- Films featuring a metal nitride such as titanium nitride (ceramic).
- Films featuring a metal oxide in combination with a metal (spectrally selective).

Sputtered films have excellent solar heat control properties like those that are produced by the metallizing process. Sputtering is a versatile process as several layers of different metals can be applied to a single piece of film (metal on metal layering), resulting in unique colors and higher levels of selective transmission. When these films are produced without an additional coloration layer, they are often warranted to not change color.

When comparing metallized versus sputtered products, metallized films will dry faster due to the more "open" crystalline structure produced by metallizing and will be less expensive due to the speed of the process. Metals used in sputtering are often less reflective than aluminum when compared at the same visible light transmission. Metallizing works best with a single metal since it relies solely on heating the metal until it reaches a gas state. It is difficult to metallize alloys since the metals in the allot melt and turn to gas at different temperatures. Sputtering is thus preferred for alloys or for depositing oxides or nitrides, but it has the disadvantage of slower-drying due to a tighter crystalline structure and higher cost due to slower processing rates. Some manufacturers have special processes for improving the drying time of sputtered products. The effect of slower drying often results in a thin water layer collecting at the sputtered surface after installation which often shows up as "haze" to the consumer. This haze may take several days to clear, and if much water is left during installation, it can pool into water pockets which can leave a permanent "water spot" even after drying. Sputtered products therefore take more care and the use of better squeegee techniques during installation. The diagram below illustrates a standard neutral sputtered film structure with a pressure sensitive adhesive.



Some of the most interesting, sputtered films are those found in the "spectrally selective" category. These films have a sputtered "stack" of coatings, as opposed to a single sputtered layer, which gives the products interesting solar properties not possible with a standard sputtered layer.

Window Film Performance Values and Measurements

There are many different combinations of technologies and materials that make up the window film automotive offering. It is important to understand the different performance values and how they are used to market and communicate the benefits of each product. In previous sections, interaction of the sun with glass was explained using the reflectance, absorptance, and transmittance values for a single pane of glass. How the absorbed energy was transferred and how transmitted energy is converted to far infrared and re-radiated was also explained. It is not necessary to explain each of these values to a consumer. Calculated values which pull all this data together into a more easily communicated message are available.

The most widely used performance value in the automotive window film industry is the Total Solar Energy Rejection which is calculated from the Solar Heat Gain Coefficient (SHGC).

Solar Heat Gain Coefficient

SHGC measures how well a product blocks heat caused by sunlight. The SHGC is the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed, then subsequently released inward. SHGC is expressed as a number between 0 and 1. The lower the SHGC, the less solar heat transmitted.

Total Solar Energy Rejection

As with many product measurements, the most scientific measurement is often not the easiest to explain to a consumer. Many people have trouble with the concept that a lower number is a higher performing product. For that reason, the window film industry has used the Total Solar Energy Rejection value to explain solar performance in automobiles. TSER = 1- SHGC expressed as a percentage. A product with a .45 SHGC would have a TSER of 55%.

Glare Reduction

Glare is a fascinating and complicated subject. Simply put, glare is the loss of visual performance when the intensity of the light in the field of vision is greater than the eyes' ability to adapt. The wavelength of the light and other factors contributes to a person's ability to deal with light. While not an all-inclusive measurement, comparing the VLT of a product to the visible light transmission of clear glass does give a relative number by which to compare products. It may be just as easy to simply compare the VLT of two products and surmise that the darker product will give better glare protection than the lighter product. With the rapidly advancing research into blue light and other factors of glare this may be too simplistic an approach for light sensitive customers.

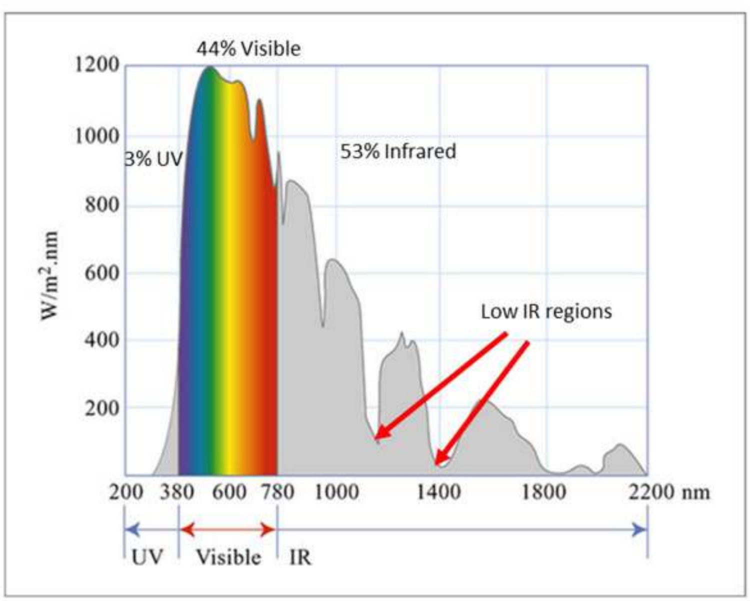
Infrared Rejection

Another performance value used in recent years is the Infrared Rejection. Often abbreviated as the IRR, this value is not defined in any national or international test method.

It's important to understand the full solar spectrum, because some companies market their products with information about infrared rejection only and use a measurement called infrared rejection, IR rejection, or IRR. This has created confusion about which rating is an accurate indicator of product performance – and it can be misleading. The IWFA has presented guidance that this value should only be used in conjunction with the TSER or SHGC values to not cause misunderstandings with consumers.

Because infrared rays are only part of the solar spectrum and only part of the sun's heat, IR rejection numbers may be higher than TSER numbers – but looking at IR rejection and TSER side-by-side isn't a direct comparison. For example: an 80% IR rejection rating means you're blocking 80% of the 53% of sun's rays that are infrared, and the film may only be blocking about 50-60% of all the sun's heat, while an 80% TSER rating means you're blocking 80% of all the sun's heat-causing rays.

Additionally, IR rejection ratings may not be measured the same way from one company to the next. One company's IR rejection rating may be based on performance in the full range of infrared rays, from 780 to 2,500 nanometers. Another company's IR rejection rating could be for an infrared range of just 900 to 1,000 nanometers – an even narrower measurement. For a true representation of heat rejection performance, always look for TSER first. It's the most useful and most accurate way to measure total heat rejection for a window film. And if you must use IR rejection numbers, look closely to be sure they're for the full range of 780 to 2,500 nanometers. The diagram below shows the actual solar spectrum by standard setting bodies in the US. Note the dips in the IR region indicated by red arrows. By picking specific wavelengths that already have lower intensity and reporting the IR values at those wavelengths, companies can present performance values that are higher than the IR values across the complete IR spectrum and significantly higher than the TSER values.



The spectrum of light emitted from the Sun. Note the peak in the green part of the spectrum. Credit: Figure by MIT OpenCourseWare.

Industry Standards

Manufacturers generally provide dealers and distributors with individual sample sheets, or sample books of their various window film offerings. These film sample sheets provide performance specifications for the respective film type. Performance values can also be found on most manufacturers' web sites. IWFA guidelines recommend the use of the National Fenestration Rating Council (NFRC) procedures for measurement, calculation, and reporting of these performance values. The data is usually based on ¼" (inch) clear monolithic, annealed glass of a particular type. Other glass types may also be shown on data sheets in addition to the ¼" glass but the glass type and thickness used for the measurements should always be included in the data sheets. NFRC works in cooperation with ASTM (American Society for Testing and Materials) and ANSI (American National Standards Institute) to make their standards the same wherever possible. Also mentioned on some data sheets will be standards from ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers) which set constants for test methods around wind speed, etc. Calculations and data in areas outside the United States may be particular to the region or use the ISO (International Standards Organization) test methods. It is important to note that the "solar spectrum" used in the various standards are not equal. There are at least three different "standard" solar spectrums used globally.

Matching Measurements to Benefits

Today the most widely marketed benefits for automotive window films are exterior aesthetics, glare control, privacy, solar heat control for occupant comfort, ultraviolet protection for fade protection and occupant skin and eye protection.

1. Exterior aesthetics are a combination of color, reflectivity, glass type and interior color. The darker the visible light transmission and the higher the visible reflectance the more noticeable the aesthetic effect. Different brands of glass use slightly different tinted glass colors even on those front side windows with light tint. Try viewing the same film on different brands of vehicle and different locations on the vehicle. Make sure to view the samples at different times of the day and in different weather conditions. The angle of the glass will also play a role in how the film looks. Bear in mind that the color of a film viewed from the outside may not be the same as the color the occupant sees when sitting in the vehicle looking out.
2. Glare control is almost exclusively a function of visible light, although the color of the light (wavelength dependent) can play a role, with blue light being a larger contributor to glare. Blue light is considered to be visible light in the range from 400nm to around 440nm, with different wavelengths contributing to macular degeneration, eye fatigue, glare, and helping to regulate sleep cycles. Early versions of blue light protection were usually seen as yellow in color, but newer versions do not have an obvious yellow tint.
3. Privacy is also related to the visible light transmission, but reflectivity plays a role in how easy it is to see into a vehicle or see the occupants. The color of the vehicle interior also

contributes to how easy it is to see the occupants, especially at night. The darker the film and the higher the reflectivity, the more privacy created. The darker the interior color of the vehicle, the darker the film will look and the more difficult it will be to see the occupants.

4. Fade protection is a function of UV protection, visible light, and heat control. The higher the UV protection, the lower the visible light transmission, and the higher the solar energy rejection, the better the fade protection. Read the additional information at the end of this section about Fade and UV.
5. Skin and eye protection are predominantly a function of UV protection although visible light transmission can also play a role. The higher and broader the UV protection and the lower the visible light transmission in the important blue light range of the spectrum, the better the protection. If your consumer has specific health needs or concerns, it is best to contact your manufacturer for additional wavelength-specific information.
6. Occupant comfort is mostly driven by heat control which is best described by the SHGC or TSER.

Ultraviolet Radiation Control

Health Considerations

As we learned from the earlier discussion about the sun and its electromagnetic radiation, invisible ultraviolet (UV) radiation represents only about 3% of the energy being transmitted in normal sunlight. However, these are very powerful and more energetic (higher frequency) rays. There are three types of ultraviolet rays: UV-C (100 to 290 nanometers), UV-B (290 to 320 nanometers) and UV-A (320 to 380 nanometers). The earth's atmosphere and ozone layer filter out most UV-C and a percentage of UV-B rays. UV-B causes sunburn, and prolonged exposure to it over many years has been linked to skin cancer, particularly basal and squamous cell cancers. Glass absorbs heavily in the UV-B range and screens most of those wavelengths. UV-A is now thought to cause 90% of skin aging and has been linked to melanoma, since the longer wavelength of the UV-A rays penetrate deeper into the skin. "Broad-spectrum" sunscreens were developed to screen UV-B and UV-A. Early sunscreens only screened in the UV-B range and allowed people to stay in the sun longer without experiencing a sunburn, thus allowing more UV-A skin damage. According to the Skin Cancer Foundation (SCF), there are about 106,000 new cases of non-invasive and 101,000 cases of invasive melanoma carcinoma and about 3.6 million basal cell and 1.8 million squamous cell skin cancers diagnosed annually in the US. There are roughly 7000 melanoma skin cancer deaths per year (2021 SCF website). Window film is designed to absorb UV-A radiation, so while glass may protect from a sunburn, the addition of window film can be a significant improvement in the blocking of aging and cancer-causing UV radiation. Studies have shown that drivers show significantly more aging and skin cancer on the side of the face next to the window when those drivers spend many hours a day in the vehicle.

Fading considerations

Fading is a complex issue because each material has a different propensity to degrade from exposure to both normal visible sunlight and ultraviolet radiation, in addition to a host of other factors. For example, wood is extremely vulnerable to fading. Similarly, papers, inks, natural plant dyes, and natural fibers are more susceptible to fading than synthetics. Most automotive interior coverings have been developed to be quite stable to the factors which impact fading, but deterioration still occurs. While the exact percentages of impact vary between auto interior materials, it can be generalized that at least six factors contribute to fading:

1. Ultraviolet radiation
2. Visible light from the sun and artificial sources
3. Heat from the sun
4. Humidity and moisture
5. Dye fastness
6. Chemical vapors in the air

Ultraviolet radiation is considered the harshest of the factors, although the percentages will differ based on the material. Going into a museum with priceless artifacts is a good lesson in understanding fading and deterioration. The light will be extremely dim, and generally it is cool, with a highly controlled humidity. Not seen is that all the lighting has extra UV radiation protection. Some exhibits require the visitor push a button which illuminates the objects for a short period of time. While vehicles do not contain great works of art or antique fabrics, it is still important to protect the interior coverings and contents from deterioration.

Dealers are encouraged to exercise caution in this area and not oversell the products' potential benefits in "preventing" fading. ***Again, no film or glazing product will totally prevent or stop fading.***

Special Installation Considerations

Radio and Phone Signals

Many vehicles today have the antenna as part of the glass. Certain films with high electrical conductivity can interfere with the receipt of sound signals or their transmittance to the radio or mobile phone. In those cases, it is advisable to use a non-metallic film type. Check with the film manufacturer for their recommendation. Some dealerships and car manufacturers may void the warranty on certain electronics if conductive film is installed on the vehicle.

Plastic Glazing

Never found in the passenger areas of vehicles, plastic glazing is sometimes found in special vehicle types or cargo areas. Cleaning plastic glazing before installation or trying to remove film from plastic glazing is problematic, and this application is not covered by most manufacturer warranties. Always check with the manufacturer before installing film on plastic glazing.

Glass Coatings

As with plastic glazing, glass coatings may be easily scratched during the installation process or damaged during film removal. Check the coating before installing window films.

Laminated Glass

New types of laminated glass are being introduced into car models every year. While all windscreens are laminated glass, there is increasing use of laminated glass in the passenger/driver front door glass and sunroofs. Additionally, these laminated structures are using special PVB for either noise reduction, solar control, or both. Some of the laminated glass has a very thin inner side glass and, while some of them are heat strengthened, consult your manufacturer about types of film compatible with these glass types.

Decals and Stickers

Often automotive glass will have stickers attached to the inside of the glass for various reasons, including sales documents or regulatory stickers. Film will adhere to the stickers, but it can present a poorer bond than applying directly to the glass, which could lead to film failure or bubbling around the sticker. Sometimes it is possible to remove the sticker and then reinstall on the film but often there are visibility requirements for the stickers which prevent this option. Additionally, it may be possible to cut around the sticker leaving a very small border around the edges.

Automotive Window Film Legal Considerations

There are vast differences in the laws pertaining to the allowed use of automotive window film around the globe. This discussion will start with the very important instruction to always check with your local authorities for the most up-to-date tint laws and enforcement policies for your area. Adhering to this policy will always give the best outcome for the dealer and the consumer. Covering the global variations in tint laws is outside the scope of this document, and the following is information specific to the United States, its states and territories. The IWFA works around the globe with its member manufacturers and distributors to promote safe and fair statutes and regulations. Information for each state, along with Canada and its provinces, can be found on the IWFA website.

NHTSA

NHTSA stands for the National Highway Traffic Safety Administration. This U.S. Federal agency regulates and enforces the laws governing all new vehicles to ensure safety on the roadways. Once the vehicle is in use, the vehicle is considered to fall under the individual state requirements for any aftermarket products. There is a distinction between trucks over 26,000 pounds and all other vehicles. Large rigs fall under the jurisdiction of the Federal Motor Carrier Safety Administration (FMCSA) once they are sold.

NHTSA has long taken the position that, except for the Do-It-Yourself kit market, window film falls under their authority and, as such, they have the right to regulate the application and use of window film on automobiles and that its regulations covering the use of glazing materials on vehicle windows applies equally to window film and not just new vehicle glazing. If ever enforced, this authority would have a devastating effect on the window film industry, as new vehicle standards have extremely high visible light transmission standards.

The industry has taken the position that window film is an "aftermarket" product, and therefore does not fall within the NHTSA jurisdiction. NHTSA's position has been tested once in court many years ago, with the court ruling on the side of state rights and the window film industry. NHTSA has never officially backed off from their position, but they have not pursued further action in over 30 years. As more and more consumers have moved to buying SUVs which sit on truck chassis and have different glazing requirements, the number of actual passenger automobiles has dropped substantially. SUVs have much darker glazing in the back portion of the vehicle than allowed in a passenger automobile. The matter, however, of NHTSA's authority to regulate automotive window film remains a complicated legal question.

FMVSS-205

FMVSS-205 stands for the Federal Motor Vehicle Safety Standard No. 205. This is the primary statute used by NHTSA when governing the use of glass and glazing materials in motor vehicles. It requires, among other things, a certain amount of visible light transmittance with respect to any window "requisite for driver visibility." Every window on a vehicle is given a classification by the US Department of Transportation. This classification ultimately determines the degree of allowed shading for each window location, taking into consideration the "requisite for driver visibility" safety concern.

- AS1 – The viewing area of the windshield is considered AS1 and has the highest visibility standard.
- AS2 – The driver and front passenger windows (and any other small vent type windows in the front cabin area).
- AS3 –The area considered outside the requisite for driver visibility, which includes the top 3-6 inches of the windshield and all windows to the rear of the driver and front passenger. These windows have much less strict limitations on visibility and light transmittance.

FMVSS205 affects all passenger automobiles but on trucks and multi-purpose vehicles is applicable only to the front side windows if the vehicle has two outside rear mirrors. This is the reason that a high percentage of vehicles on the road today have tinted factory glass on the rear glazing.

State Laws

Unlike the federal laws, state tinting laws fall under the aftermarket portion of the automotive state laws. Every state has its own laws regarding the application of window film to vehicle windows. Anyone, including the vehicle owner, operator, and/or film installer, violating his own state's window tinting laws may be subject to prosecution under that state's laws. Usually, the violation is enforced with fines which in some cases can be quite high. The IWFA works year-around to improve or maintain state law language that is responsible and easy to enforce.

All state laws have some language around the visibility of the driver and most define a minimum visible light transmittance. Since it is almost impossible to measure the window film itself after installation, most state laws have a "net" VLT requirement which is the combination of the film on the glass. Most motor vehicle windows have some tint to them and are allowed by FM205 to be as dark as 70% although most are slightly lighter. Since window film visible light transmission is tested and reported on clear glass it is important to know what the measurement will be on tinted automotive glass. Portable, hand-held light meters are available at a reasonable price and shops should have them to check the combination of film and glass when in doubt.

IWFA supports reasonable and enforceable laws and works with law enforcement to obtain and train personnel in the use of the meters for proper enforcement of local laws. The best laws are written with a tolerance that covers the slight variations in meters and calibration effects. Those tolerances average around 5% but may be as little as 3% or as much as 7%. In some states no tolerance is allowed from the statutes.

In addition to the laws, each state has a particular agency responsible for enforcement of those laws and regulations on how the law is enforced. It is not enough to know the law, but the regulations must also be known to make sure the tint installation is considered legal in the state.

In addition to the visible light transmittance, some state laws regulate the visible light reflectance or contain language around not having "reflective" films installed. For a discussion on reflectivity, please refer back to that section in the guide.

IWFA maintains a State Tint Law Chart on their website at www.iwfa.com.

Changing or creating a new State Tint law can be a challenging, long process. IWFA monitors all legislatures and regulatory bodies for any bills or changes which will impact window film negatively. The IWFA promotes fair, safe, and measurable standards for the use of window film in each state. Contact the IWFA office for more information about issues in your state and to discuss the IWFA Model legislation that has been used successfully in many states. It is not just getting someone in the state legislature to introduce a bill. All constituents must be involved in the process, and many good proposals have never made it out of committee because of a failure to involve law enforcement or other interested parties. IWFA often provides training sessions so those involved can actually see what films look like on cars and not react to previous erroneous assumptions.